

Design & development of Boron-doped graphene materials for environmental applications

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ABSTRACT

Boron engineering of graphene-based materials has emerged as a powerful approach to modulate the intrinsic physicochemical limitations of pristine graphene.[1] While graphene exhibits outstanding electrical conductivity and high specific surface area, its chemically inert basal plane restricts its performance in environmental remediation.[2] Substitutional boron doping introduces electron-deficient sites within the carbon lattice, alters charge density distribution, induces p-type characteristics, and generates structural defects that act as catalytically active centers. Such electronic and structural perturbations have been shown to significantly enhance electrochemical activity, surface reactivity, and pollutant degradation efficiency, highlighting boron incorporation as a key strategy for next-generation graphene-based environmental materials.[3] In this work, we develop a systematic materials platform spanning low, medium, and ultra-high boron concentrations in two-dimensional carbon frameworks. Three distinct classes of boron-containing graphene-based materials were synthesized, spanning a broad compositional range from ~1.6 and ~6.5 at% up to 50 at% boron. Beyond conventional boron-doped graphene systems, we investigate a next-generation 2D boron–carbon material inspired by the Zintl phase CaB_2C_2 , targeting the experimentally unrealized hydrogenated structure $\text{H}_2\text{B}_2\text{C}_2$. This graphene-analogue material, denoted as borographane, represents a boron-rich 2D network with anticipated high surface area. By bridging controlled boron doping with the development of a highly boron-enriched 2D framework, this study elucidates structure–composition–function relationships and advances the implementation of boron-engineered graphene materials in environmental technologies.

Among the contaminants that influence the hazardousness of wastewater, organic pollutants such as pharmaceuticals and dyes, as well as heavy metals are regarded as particularly concerning due to their toxicity, persistence, and potential to bioaccumulate in the environment. Thus, removing these dangerous substances from water is critical because they impair both human health and water quality. Several treatment techniques have been employed, but adsorption has shined out as an easy, efficient and effective method. As model pollutants Rhodamine B, Ketoprofen and Cr(VI) have been selected, due to their toxicity and persistence in wastewaters.

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